Perspectives on NASA Onboard Processing Needs for Future Space Missions

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Topics

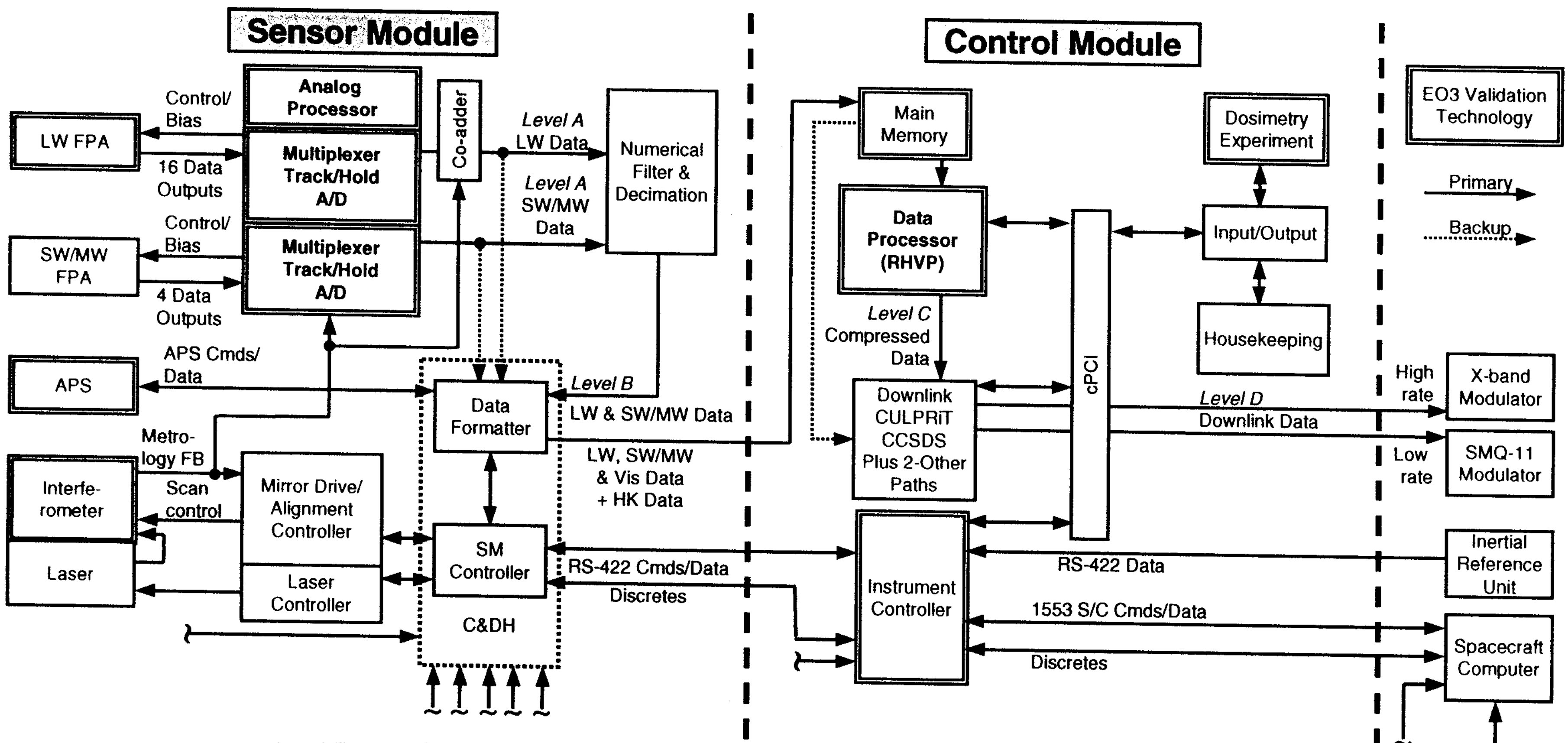
- Background Information
- Emerging Scenarios for Science Data Acquisition
  - Earth Observation Missions
  - Deep Space Missions
- Downlink Bottlenecks/Need for a Paradigm Shift
- Validating the Paradigm Shift -- New Millennium Technology Validation Flights
- Summary

Background -- How We Do Things Today

- Manpower intensive processes and procedures for S/C operations, health monitoring and problem fixing solving
- Dealing with science data
  - Data compression
    *Both lossless and lossy algorithms used
    *Choice of compression method depends on application
  - Encode/Packetize
  - Downlink

This scheme works fine if there is sufficient downlink bandwidth and manpower available

EO3 (GIFTS) Signal Processing Chain



GIFTS is a significant step forward in the application of onboard processing for Earth-observation missions

Future Developments that will Affect Management of NASA Space Assets

- Formation flying of different S/C to observe the same object on the Earth's surface (large amounts of data generated)
- Constellations of satellites around Earth and other planets
  - Observe Sun/Earth interactions
  - Mars Network
- Many other deep space missions in progress simultaneously

Deep Space Network will have difficulty monitoring missions and downlink bandwidth for Earth observing S/C won't be able to handle the data rates

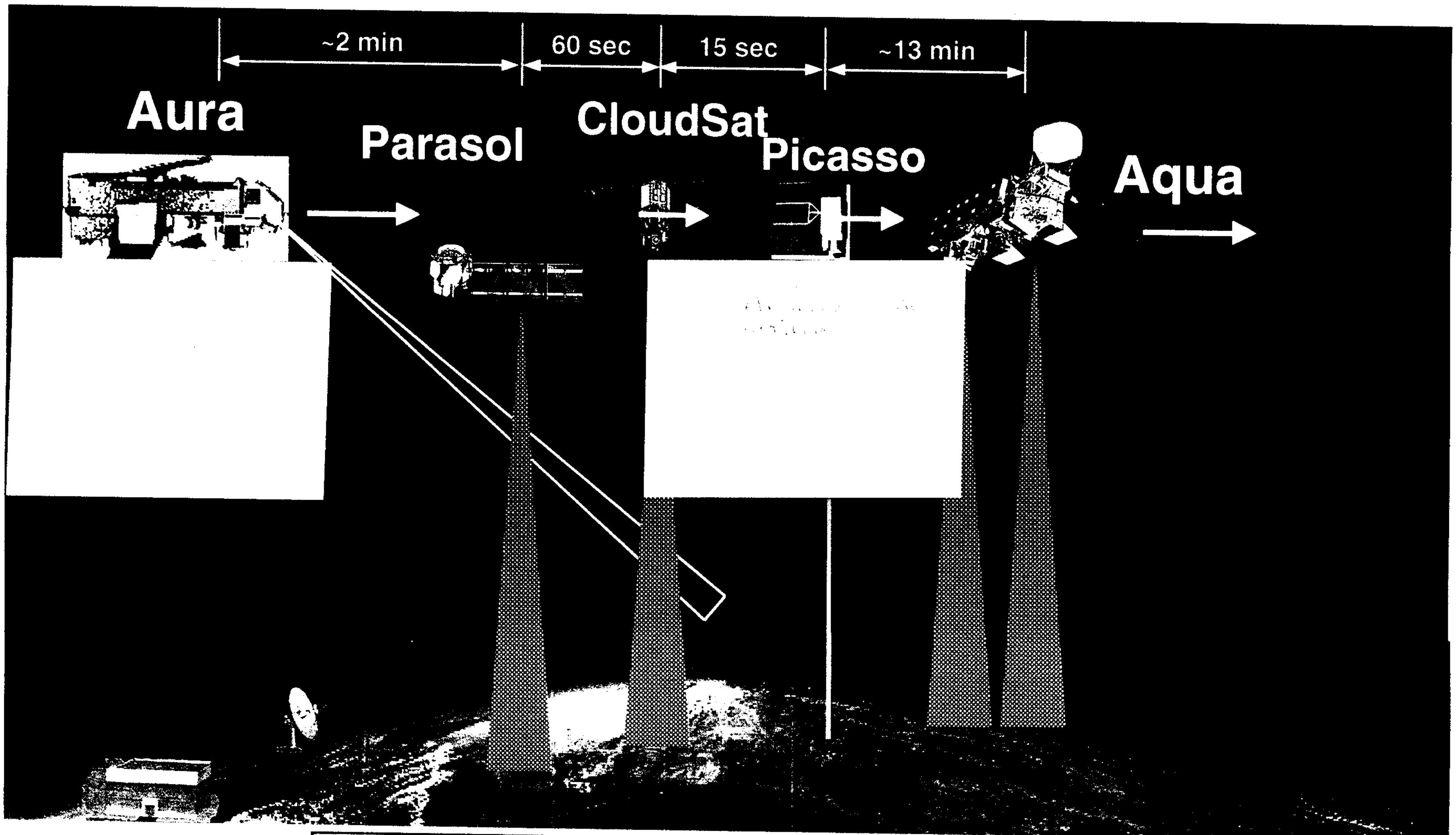
Data Rate Trends for High Data Rate Instruments on Earth-Observing Spacecraft

Instrument	Technology Readiness Date 2000	2003	2006
Hyperspectral	1.6 Gbps	3.2 Gbps	40.3 Gbps
SAR	0.18 Gbps	1.3 Gbps	4.8 Gbps
LIDAR	5.0 Mbps	5.0 Mbps	5.0 Mbps

(Source: JPL, [illegible]
High Data Rate Instrument Study)

These high data rate instruments will be built; the question is what percentage of the data can be cost-effectively stored and transmitted

PM Train: Formation Flying Concept for Earth-Observing Spacecraft



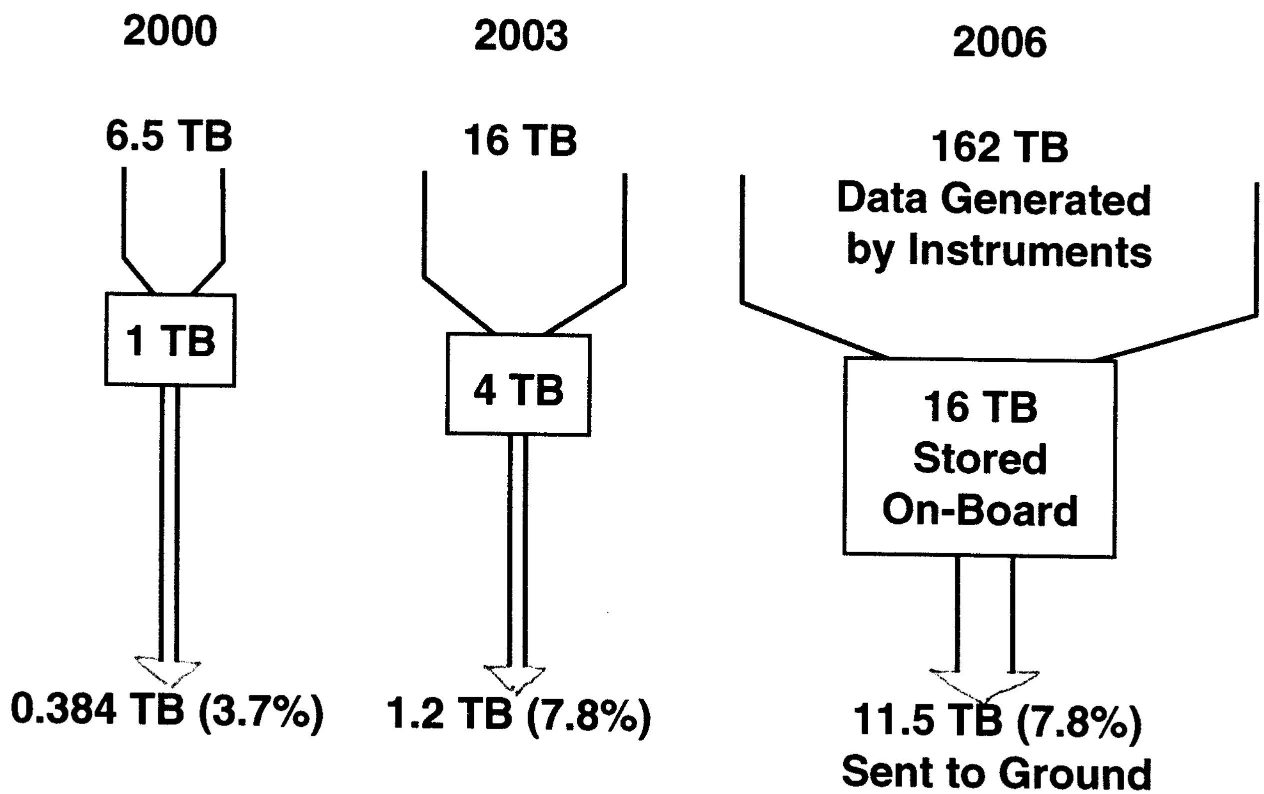
That Poor Guy on the Ground ☹

Constellations of Spacecraft for Deep Space Science Missions

	Mission	Number of Spacecraft	S/C Mass, kg	Orbit
Near-Term	Magnetospheric Multiscale	5	240	Apogees from 12 to 12 Re
	Geospace Electrodynamic Connections	4	600	130 x 2000 km
	Mag Constellation	100	10	10 – 35 Re
Mid-Term	Inner Mag Constellation	42	10	2 – 12 Re
Far-Term	Dayside Boundary Constellation	39	10	2 – 20 Re
	Solar Flotilla	12	50	Heliocentric (Perihelion ~0.2 AU), Various Inclinations
	Inner Heliospheric	12	50	Heliocentric (Perihelion ~0.2 AU), Various Inclinations

Monitoring these spaces plus those associated with other missions severely strains the Deep Space Network ☹

Downlink Bottlenecks



Only 1-10% of the data will get to the ground
CRF case – two orbits of data

Source: JPL Publication 99-4;
High Data Rate Instrument Study

Autonomy/Onboard Processing -- One Approach to for Alleviating Downlink Bottleneck and Overloaded Deep Space Network Problems

- **Autonomy "cuts" across all spacecraft subsystems**
  - The primary S/C functional elements, i.E., power, propulsion, GNC, CGH, are managed in real-time thus relieving workload on ground controllers:
    - GNC sensors to characterize environment
    - GNC actuators to maneuver for observations or avoidance hazard
    - Navigation and instrument control to make observations
    - Data storage/memory, data information extraction, communications of opportunity
    - Payload care, control and protection in uncertain environments
- **Most deep space missions can benefit from S/C autonomy**
  - Deep space communications latency times and unknown environments make ground intervention for near real-time (hours for comet missions and seconds for Landers) decision making virtually impossible:
    - System autonomy is needed to achieve goal(s) or sub-goals
    - System on-board decision making to close planning and control loops
- **Autonomy "cuts" across all mission disciplines**

  Engineers
  - Mission design
  - S/C design
  - Mission operations

  Scientist (onboard processing to relieve data rate bottleneck)
  - Observation design
  - Science data analysis
  - Instrument operations
- **Autonomy "cuts" across a multiplicity of space missions**
  - Single S/C, Rovers, Constellations, Landers, Insitu Laboratories

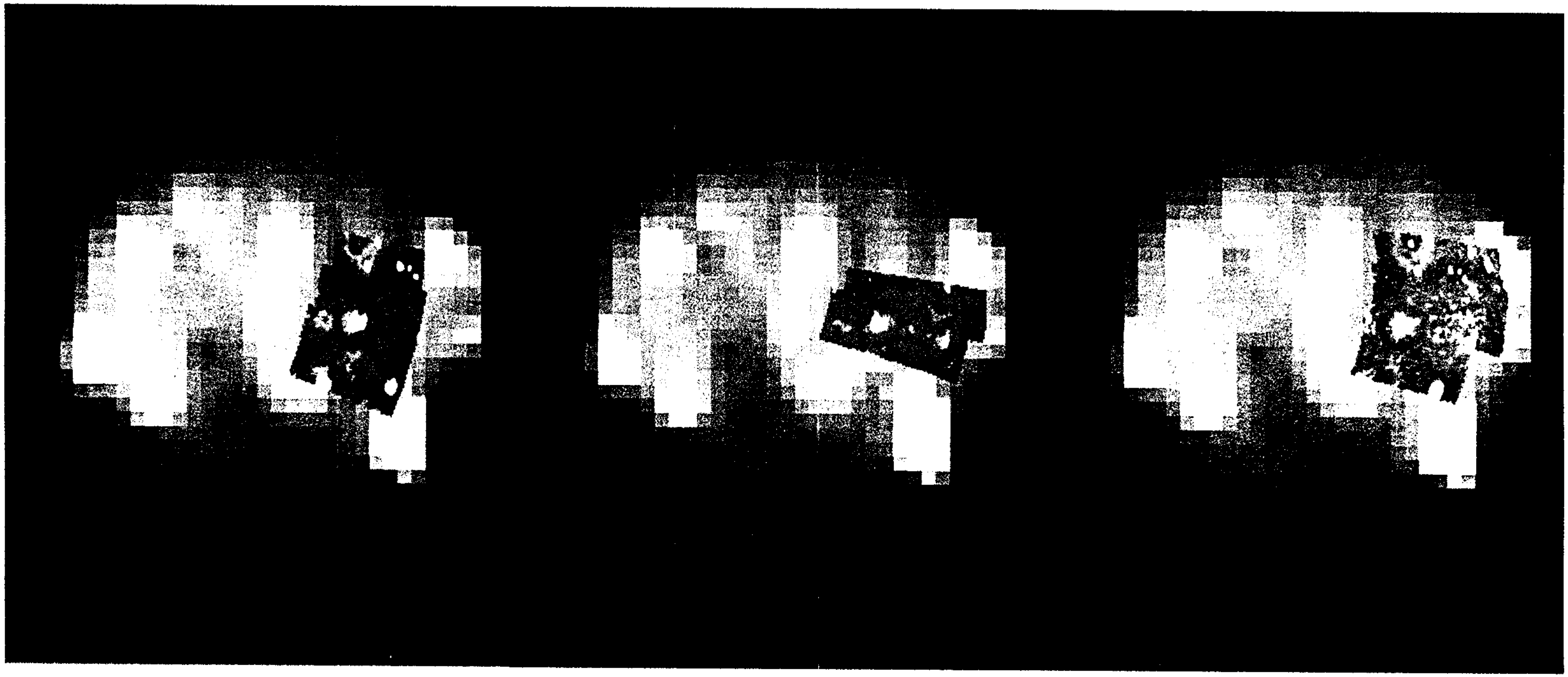
Potential Applications for Autonomy/Onboard Processing for Earth Observation Missions

- Autonomy (minimize intervention from ground controllers)
  - Orbit maintenance (for single S/C)
  - Fix problems on S/C
  - Constellation configuration/reconfiguration, maintenance and control
- Onboard processing (detecting/acting on changes)
  - Active volcanoes
  - Track storms/floods
  - Track iceberg formation/movement
  - Other applications

Potential Applications for Autonomy/Onboard Processing for Deep Space Missions

- Autonomy
  - Plan/execute mission without intervention from ground controllers
  - Fix problems on S/C without intervention from ground controllers
  - Constellation configuration/reconfiguration, maintenance and control
- Onboard processing
  - Quick response to stellar events (gamma ray bursts, solar flares, etc.)
  - Planetary imaging
    - Volcanic eruptions on Io
    - Crustal ice movement on europa
    - Advance/retreat of Mars polar caps
  - Other applications
- Management of information from Mars Network

Volcanic Eruptions on Io: Example of Capturing Opportunistic Science



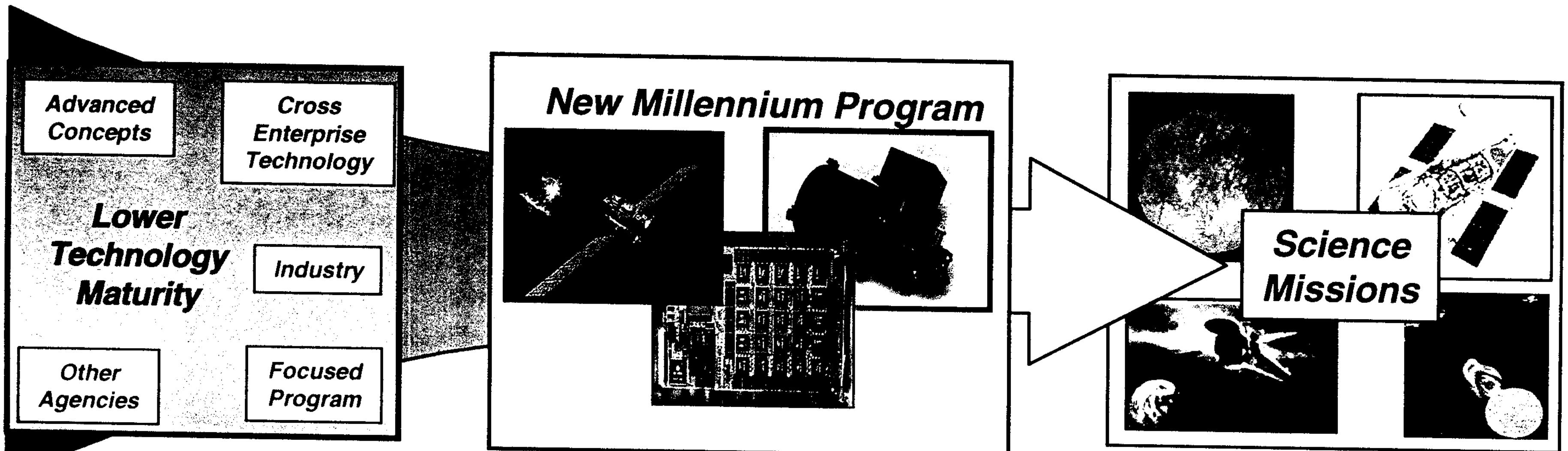
October, 1999 November, 1999 February, 2000

Increased Volcanic Activity Detected

Impediments to Implementing Autonomy/Onboard Processing in NASA Space Missions

- Implies major procedural changes
  - New design, simulation, and operation procedures
  - Major paradigm shift leading to fear of losing control
- Combined effects of system/subsystem complexity

The New Millennium Program Fills a Critical Role in Space Science Technology Development



Technology Development

Technology Validation/ Risk Reduction/ Technology Infusion

Technology Acceptance

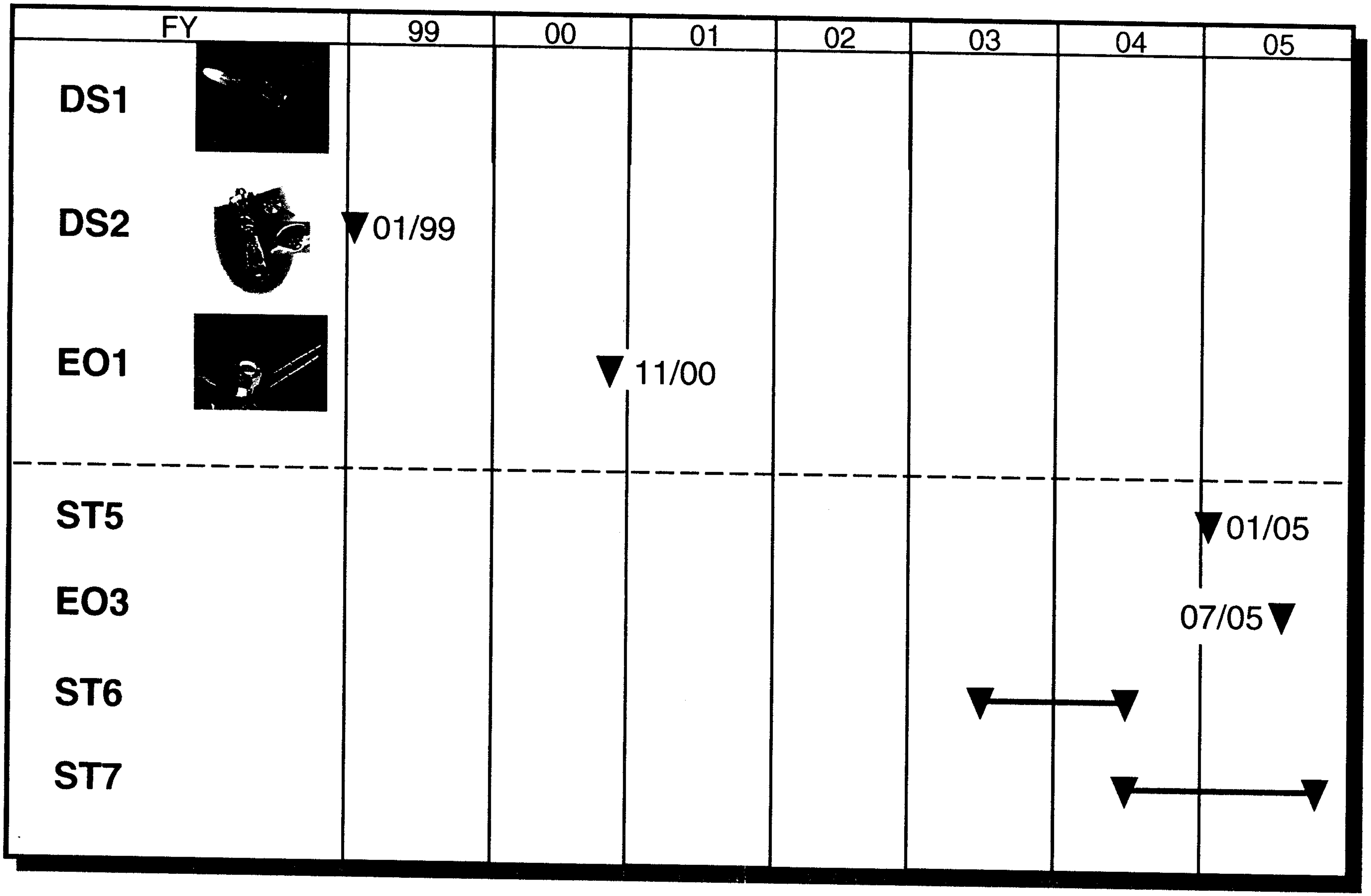
Autonomy/Onboard Processing Technologies Being Validated on NMP Missions

Autonomy Technologies	DS1	EO1				ST7*
Guidance Navigation & Control						
• Onboard trajectory determination	■					■
• Trajectory planning	■					■
• Maneuver design & execution	■					■
• Feature identification and tracking						■
• Target relative maneuvering						■
• Hazard collision avoidance						
Multiple S/C						
• Formation keeping			■	■		
• Coordinated Platforms						
❑ Resource sharing						
❑ Science data gathering			■	■		
❑ Information fusion						
Science observation						
• Engineering sensor data fusion	■			■	■	
• Science data fusion					■	
• Re-targeting to repeat science observations					■	■
• Capture opportunistic science					■	
• Optimize science downlink data					■	
• Onboard science event detection				■		

Autonomy Technologies	DS1	EO1				ST7*
Goal-based commanding						
• Task decomposition	■					■
• Automated sequencing	■					■
• Event driven sequencing						■
Onboard planning						
• Automated planning	■					
• Planning in uncertain environments						■
• Dynamic planning & plan optimization						
• Contingency planning						
• Real time scheduling						■
S/C resources						
• Resource management and optimization				■		■
• Self monitoring and selective health reporting				■		■
Anomaly resolution						
• Model-based fault protection	■					■
• Flexible contingent response						
• Response to unanticipated faults						
Autonomous Mission Operations						
• Autonomous scheduling of ground stations				■		

*** Technologies are currently in competitive selection phase of project**

Launch Schedule for NMP Validation Flight



Stay Tuned!

- ST6 Downselect for Formulation Refinement -- 12/01
- ST7 Technology Selection Announcement -- 7/01
- New Millennium Program Website

  www://nmp.jpl.nasa.gov
- NASA Office of Space Science Roadmaps

http://sse.jpl.nasa.gov	(Solar System Exploration)
http://universe.gsfc.nasa.gov	(Structure & Evolution of the Universe)
http://sec.gsfc.nasa.gov	(Sun - Earth Connection)
http://origins.jpl.nasa.gov	(Origins)

- NASA Office of Earth Science Roadmaps

  http://esto.nasa.gov

Summary

- Autonomy/onboard processing techniques offer solutions to complex problems anticipated for future NASA science missions
- Implementation of autonomy/onboard processing requires a major paradigm shift ⇨ acceptance will be slow in coming
- Nasa's New Millennium program is validating autonomy and onboard processing technologies for future science missions to mitigate risk to first users in science missions